

Environmental Improvement Of Geotechnical Characteristics Of Weak Soils Using Polymers And Recycled Rubber Components

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Abstract

Many construction projects are required to be erected on soils characterized as weak or problematic. Weak soils need to modify and improving their properties to create a solid layer for shallow foundations and pavements. In addition, from an environmental perspective, the possible use of waste tires in soil improvement has been considered as it has few adverse environmental effects. The presence of waste rubber fiber and rubber powder has not been used in the soils improved by traditional materials, because their use leads to a decrease in the resistance of the lime concrete. In this research, the effects of adding different amounts of waste rubber and waste rubber fibers on the mechanical features of treated lime and lime-fly ash additives are investigated. Results shows that the addition of rubber powder slightly reduces the compressive strength of the improved soil. Meanwhile, the use of rubber fibers significantly improves the compressive strength, ductility, fracture strain, as well as the moduli of elasticity, bulk, and shear strength in all processing times. Also, adding 12% of waste rubber powder and 1% of rubber fibers to the lime and lime-fly ash additive can provide good and reduces adverse environmental effects.

Keywords: Improvement, fly ash, waste tires, weak soil.

1. Introduction

In many construction activities, there is an unavoidable need to use weak and problematic local soils. Economic considerations, non-availability of quality materials and transportation distances often justify soil improvement. Poor quality soils can indicate poor quality soils usually exhibit unfavorable behavior such as expansive and shrinkage behavior, low bearing capacity and high moisture sensitivity. Clay soils and blown sand soils in desert areas are amongst the problematic soils in road building and construction projects. Hence, geotechnical engineers are looking for practical and economic methods to resolve these problems. Stabilization of these types of soils using different additives would be a natural issue since replacing foundation materials with high quality soils is so costly. The most widely used additive for stabilizing clay soils and improving their attributes from the past to recent years is lime and then cement (Jahandari, Mohammadi, et al., 2021).

Among the first research studies performed on lime-stabilized soils is the investigation conducted in 1981 towards improving the properties of fine-grained soils. The results of that study have shown that the percentage of lime needed to increase and improve the properties of fine-grained soils is between 3 and 8% (Mitchell, 1981). In addition, lime concrete and lime mortar are widely used in various construction projects. (Malekpoor & Toufigh, 2010) reported that lime concrete columns containing 20% lime and 22% clay significantly improve the bearing capacity of problematic soils. (Stefanidou & Papayianni,

2005) investigated the effects of the amount and size of aggregate on the characteristics of lime concrete. In their research, different mixes were prepared with different percentage of lime-to-aggregate and water-to-lime ratios. The results showed that the coarse aggregates in the lime concrete have no significant effects on the strength of the mortar, although the capillary pores are greatly reduced due to compaction. Also, the maximum strength of lime concrete is obtained by reducing the ratio of lime-to-aggregate up to 0 to 4 mm.

(Saberian, Jahandari, Li, & Zivari, 2017) investigated the effect of capillarity phenomenon and the rise of groundwater table upon the mechanical properties of lime concrete by conducting experiments and using a mathematical model. The results showed that the phenomenon of capillarity and the rise of the groundwater level causes a decrease in the resistance properties of lime concrete [5]. (Jamshidi, Mokhberi, Vakili, & Nasehi, 2023) studied the effect of chitosan bio-polymer on the mechanical properties of marly clays. The result shows Chitosan was able to increase the mechanical and dynamic characteristics of marly clays, such as unconfined pressure and shear wave velocity and maximum shear modulus [6].

The use of fly ash, blast-furnace slag and rice husk with lime for the sustainable development of the ecosystem as well as for stabilizing and improving the strength of problematic soil has been cited by some researchers (Bhanumathidas, Kalidas, & Inswareb, 2005; Higgins, 2005; Muntohar, 2009; Pal & Ghosh, 2014) [7-10]. However, the use of fly ash alone may not be sufficient to improve the geotechnical features of clay for road construction and foundation design. Therefore, fly ash together with lime is a suitable option which has drawn the attention of researchers for improving soil characteristics. (Sivapullaiah, Prashanth, & Sridharan, 1995) reported that adding fly ash with lime to the soil increases the plasticity of the latter. Although the Improvement of soil plasticity is more noticeable by adding 1% gypsum to this composition.

On the other hand, increasing attention to environmental challenges has inspired researchers to use new or recycled materials to improve engineering properties and reduce environmental concerns (Farhangi & Karakouzian, 2020; Hanaei, Sarmadi, Rezaee, & Rahmani, 2021; Jahandari, Tao, & Alim, 2021; Mehdizadeh et al., 2021; Mehrabi et al., 2021; Mohammadifar et al., 2022; Rezaia et al., 2020a; Roshani, Kargar, Farhangi, & Karakouzian, 2021)[12-20]. The effect of using a geogrid layer on the modulus of elasticity of samples containing cement and lime mortar was studied. The experimental results showed that the highest modulus of elasticity corresponded to the highest cement-to-lime ratio. The optimal amount of cement should not be more than 5%. They showed that the use of geogrid layer in a mixture of sand and cement under a constant rate of energy reduces the specific weight of soil (Azadegan & Pourebrahim, 2010; Farhangi & Karakouzian, 2020).

In another group of studies, the effect of increasing different percentages of rubber powder on the mechanical properties of clay has been explored. The results of studies done by (Mohammadifar et al., 2022) showed that the addition of tire powder has a positive effect on reducing Atterberg limits, improving strength and permeability, and reducing swelling potential and soil specific weight. Therefore, it is a suitable additive to increase soil properties. In 2004, (Phani Kumar & Sharma, 2004) investigated the effect of fly ash addition on engineering characteristics of swelling soils including hydraulic conductivity, plasticity, density, and strength. Their results indicated that by adding 20% of fly ash, the flexibility declines by about 20%. It is also reported that, depending on the type of soil, the effective amount of fly ash for improving soil engineering properties runs between 15 and 30%. Laboratory research conducted by (Dahale, Nagarnaik, & Gajbhiye, 2016) on soils stabilized with fly ash and hydrated lime showed that fly ash considerably changes the resistance properties of clay. Also, adding up to 50% of fly ash is conducive to increasing the resistance properties of the soil, while applying more than this amount reduces the overall strength of the soil. (Signes, Garzón-Roca, Fernández, de la Torre, & Franco, 2016) prepared a mixture of swelling soil with 6% different scrap rubber obtained from waste tires. The results showed that the addition of scrap rubber up to 2.5% significantly enhances the compressive strength, to reach 430 kPa.

Although many of the past investigations have been carried out on soil stabilized with lime and lime concrete, few studies have been done to evaluate the mechanical properties of soil improved with the combination of traditional and/or recycled materials. Previous researchers have recommended the

possibility of using waste tires in lime concretes to reduce their negative environmental effects. However, rubber has not been widely used in practice because its use leads to a decrease in the strength of soil improved with lime. As for limestone and fly ash-lime concretes, achieving high resistance values is not necessary and cost-effective, so the use of scrap waste rubber seems more logical. This research comprehensively evaluates the effects of adding rubber powder and rubber fibers as well as the processing time on various mechanical features of lime and fly ash-lime concretes through more than 400 experiments.

2. Materials and Methods

2.1. Materials

The soil used in the lime concrete was obtained from the Allahabad sand mine, Kerman, Iran, and the fine-grained clay soil was obtained from an area in Kerman city with geographical coordinates of 57.380 and 30.289 from the depths of 1 to 3 meters. In order to examine the behavior of the soil, initial experiments were done on the soil with the results presented in Figure (1) and Table (1). According to the classification criteria of ASTM regulations, the required soil is clay type with low plasticity and the lime used in this research is hydrated lime with a high percentage of hydrated elements (C25-19, 2019). The fly ash used for the production of fly ash-lime concrete samples was obtained from Zarand Factory, Kerman, Iran. Table (2) gives the specifications of these materials. The rubber particles used were purchased directly from Barez Rubber Factory, Kerman. The diameter of these particles is between 0.2 and 2 mm. Also, the rubber fibers have a diameter of 0.2 mm, a length of 2 to 25 mm, a tensile strength of 180 MPa, and a melting point of 220 °C. According to the recommendations of previous studies, tap water has been used for molding samples and distilled water was used for characterization experiments (Afshar et al., 2020; Darvishi, Vosoughifar, Saeidijam, Torabi, & Rahmani, 2020; Kazemi et al., 2020; Parsajoo, Armaghani, Mohammed, Khari, & Jahandari, 2021; Rezanian et al., 2020b; Saberian et al., 2017; Toghroli et al., 2020; Vali et al., 2019). Pictures related to the materials are portrayed in Figure 2. Also, the chemical analysis of the used lime is shown in Figure 3.

Unconfined compressive strength (UCS) tests were performed on all samples. In the ASTM D 5102 standard, criteria for performing unconfined tests on lime concretes are presented (ASTM, 1996). Accordingly, the axial strain value should not exceed 5% of the sample's height and the loading speed should fall between 0.5 and 2 mm/min. In this research, the loading speed of the device is set and controlled to be 1 mm/min. After two days, the samples were taken out of the mold and placed in plastic for .

The unconfined experiment was conducted after the necessary controls to accurately apply the load to the center of the sample and the loading speed. After the experiments, the final unconfined strength curves of the samples and the corresponding axial strain were taken. Secant modulus is used to evaluate the strength of lime concrete against deformation. This coefficient was calculated via dividing 50% of the maximum compressive strength by the corresponding axial strain [43]. Bulk modulus (K) measures the strength of the samples against pressure and was calculated through equation (1) below (Fishman, 1994).

$$K = \frac{\sigma}{\frac{\Delta V}{V}} = \frac{\sigma}{\varepsilon_{xx} + \varepsilon_{yy} + \varepsilon_{zz}} = E_s \frac{MPa}{3(1-2\nu)} \quad (1)$$

Here in this equation, $(\Delta V/V)$ represents volume changes, σ stands for the hydrostatic pressure, ε_{xx} , ε_{yy} and ε_{zz} , respectively, show the direction of direct strains parallel to the x, y and z axes, ν is Poisson's ratio, which is taken as 0.3 according to the soil conditions, and E_s is the elasticity coefficient of the soil. To study the strength of the samples against transverse deformation, the shear modulus of the samples was calculated according to equation (2) as follows (Ghourchian, Wyrzykowski, Lura, & Research, 2016).

$$G(MPa) = \frac{\sigma_{xy}}{\varepsilon_{xy} + \varepsilon_{yz}} = \frac{\sigma_{xy}}{2\varepsilon_{xy}} = \frac{\sigma_{xy}}{\gamma_{xy}} = E_s \frac{MPa}{2(1+\theta)} \quad (2)$$

According to AASHTO T307, modulus of elasticity is a parameter to measure the elastic response of soil to stress. Some parameters affecting this coefficient include soil type (coarse-grained or fine-grained), loading conditions, soil amount and soil density. This coefficient is obtained according to equation (3) as follows (T307-99, 2017).

$$M_R(\text{MPa})=0.124 \times \text{UCS}(\text{KPa})+68.8 \quad (3)$$

Figure 1: Particle size analysis of coarse-grained soils and the fine-grained soils used in study

Figure 2: Used materials (a) fly ash (b) rubber powder (c) rubber fibers

Table 1: Table 2. Mechanical properties of the studied soils

Reference	Properties	Results
Fine grained soil (Clay)		
ASTM 2487-11 (2011)	Type of fine-grained soil	CL
Das (2008)	Mineral of clay	Kaolinite
ASTM D422-63 (2002)	Effective size of clay (D_{10})	0.0015
Das (2008)	Activity degree of clay	0.47
ASTM D422-63 (2002)	Coefficient of curvature (C_c) of clay	0.4
ASTM D422-63 (2002)	Uniformity coefficient (C_u) of clay	18
ASTM D424-54 (1982)	Plastic limit of clay	25%
ASTM D423-66 (1972)	Liquid limit of clay	33%
ASTM D854-10 (2010)	Specific gravity of clay	2.46
Das (2008)	Plasticity index of clay	8%
AASHTO T180 (2010)	Optimum moisture of clay	15%
AASHTO T180 (2010)	Maximum specific weight of dry clay	18.74 kN/m ³
coarse-grained soils (SW-SM)		
ASTM 2487-11 (2011)	Type of coarse-grained soil	SW-SM
ASTM D422-63 (2002)	Uniformity coefficient (C_u) of SW-SM	34
ASTM D422-63 (2002)	Coefficient of curvature (C_c)	1.88
ASTM D422-63 (2002)	Effective size (D_{10}) of SW-SM	0.1
ASTM D424-54 (1982)	Plastic limit of SW-SM	14%
ASTM D423-66 (1972)	Liquid limit of SW-SM	27%
Das (2008)	Plasticity index of SW-SM	13%

Table 3: Chemical features of used fly ash

SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	tiO ₂	CaO	V ₂ O ₅	So ₃	K ₂ O
55.8	27.9	7.09	2.25	3.96	0.09	0.32	1.55

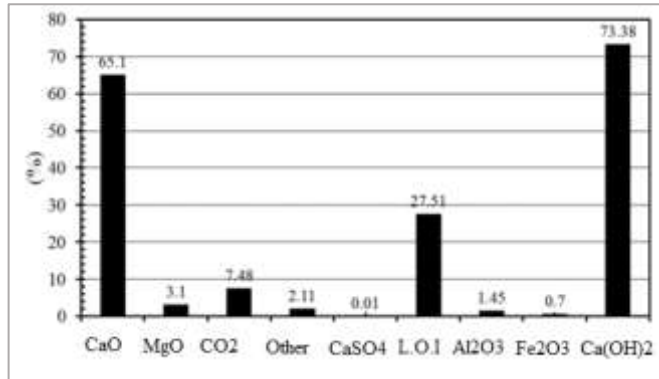


Figure 3: Results of chemical analysis of lime used in this research

3. Discussion

Based on the main objective of the current research to investigate, the effects of adding different percentages of rubber powder and rubber fibers on the mechanical attributes of lime and fly-ash concrete at different processing times, the mixing programs are mentioned in Tables 3 and 4. Following describes the obtained results.

3.1. Mechanical properties of lime concrete with and without additives

Table (5) contains a summary of the results pertaining to measuring the mechanical parameters of lime concrete samples with rubber powder, and Table (6) shows the mechanical parameters of lime concrete samples with rubber fibers. In Figs. (4) to (16) the results are shown separately.

3.1.1. Lime concrete without additives

Fig. (4) depicts the relationship between the maximum compressive strength of the samples containing lime with the increase in the processing time. Based on the findings, the increase of processing time from 3 to 90 days coincided with an increase in the compressive strength from 200 to 350 MPa. However, increasing the processing time from 28 to 90 days resulted in an enhancement of about 3% which is the lowest observed rate. Indeed, after 28 days, the rate of increase in strength reduces. As regards the fracture strain related to the maximum compressive strength, we are facing a decreasing trend as the processing time increases, as seen in Figure (4). In the processing time of 90 days, compared to the processing time of 3 days,

Table 4: Geotechnical parameters of lime concrete with different percentages of rubber powder

Mix design	additive	sand (kg/m ³)	Clay (kg/m ³)	lime (kg/m ³)	The amount of additive		Water (kg/m ³)
					%	(kg/m ³)	
1	No additive	1000	230	170	0	0	336
		960	230	170	4	40	336
2	Rubber powder	920	230	170	8	80	336
		880	230	170	12	120	336
		840	230	170	16	160	336
		800	230	170	20	200	336
		800	230	170	20	200	336

3	Rubber fibers	750	230	170	25	250	336
		700	230	170	30	300	336
		995	230	170	0.5	5	336
		990	230	170	1	10	336
		985	230	170	1.5	15	336
		980	230	170	2	20	336

Table 5: Geotechnical parameters of lime concrete with different percentages of rubber fibers

Mix design	Sand (kg/m ³)	Clay (kg/m ³)	Lime (kg/m ³)	Geopolymer (kg/m ³)	The amount of additive		Water (kg/m ³)
					%	(kg/m ³)	
No additive	1000	230	85	85	0	0	336
Rubber powder	960	230	85	85	4	40	336
	920	230	85	85	8	80	336
	880	230	85	85	12	120	336
	840	230	85	85	16	160	336
	800	230	85	85	20	200	336
	750	230	85	85	25	250	336
	700	230	85	85	30	300	336
Rubber fibers	995	230	85	85	0.5	5	336
	990	230	85	85	1	10	336
	985	230	85	85	1.5	15	336
	980	230	85	85	2	20	336

the fracture strain was diminished by 37.5%. According to Figure (4), parallel with the increasing processing time, the secant modulus grows due to the increase in the pozzolanic reactions and decreasing water. The highest rate of 41% increase in the secant modulus corresponds to the growth in the processing time from 7 to 28 days. A 30% increase in the secant modulus is observed when the processing time increased from 28 days to 90 days.

Since there is a direct relationship between the bulk modulus and secant, as expected, the bulk modulus also increased significantly with the increase in processing time. Also, due to the fact that the modulus of elasticity has a direct and linear relationship with USC, this parameter also increased with the increment in the processing time. By increasing the processing time from 3 to 7 days, the modulus of elasticity exhibited an increase from 93.4 to 102.08 MPa, while by increasing the former from 28 to 90, the latter increased from 110.76 to 112 MPa. As with the secant and bulk modulus, the same trend holds for the shear modulus. According to the obtained results, these samples will be examined as the reference for comparison with the other samples that contain additives.

3.1.2. Lime concrete containing rubber powder

Figure (5) illustrates the effect of adding different percentages of rubber powder on the maximum compressive strength of lime concrete at various processing times. By increasing the percentage of rubber powder in all the processing times, the maximum compressive strength would be less than that of the lime concrete sample without rubber powder. However, in all samples with different percentages of rubber powder, the compressive strength increases with the increment in the processing time. For example, the

highest strength of 341 MPa occurred in the sample with 4% rubber powder and a processing time of 90 days, compared to a similar sample of lime concrete without rubber powder and a similar processing time which has decreased to a negligible rate about 2.5%. Therefore, the sample containing 4% rubber powder is comparable to the lime concrete sample without rubber powder in terms of compressive strength.

Figure (6) shows the effect of adding different percentages of rubber powder on the fracture strain of lime concrete at different processing times. According to the results, the failure strains of the samples with different percentages of rubber powder is higher than those of the lime concrete samples without additives at all processing times. It indicates the more ductile behavior of the samples containing rubber powder. Besides, with the increase in the processing time in all the samples containing rubber powder, the fracture strain was seen to be decreased. Also, by increasing the processing time from 3 to 7 days, the fracture strain decreased by 5-10%, while as the former rose from 28 to 90 days, the latter showed a reduction of about 10-20%. It is also worth noting that when the percentage of rubber powder increased, the fracture strain of the samples increased as well at the same processing times. For example, the fracture strain of the sample containing 4% rubber powder during 90 days processing time is about 1.39%, while that of the sample containing 30% rubber powder during the same processing time was reported to be about 1.99%.

Figure (7) shows the effect of adding percentages of rubber powder on the modulus of elasticity of lime concrete at different processing times. According to the observed results, the modulus of elasticity of the samples containing different percentages of rubber powder is lower than that of the lime shaft samples at similar processing times. Another point is that increasing the percentage of rubber powder in all processing times causes a drop in the modulus of elasticity, although increasing the processing time intensifies the modulus of elasticity in different percentages. The highest value of secant modulus for the sample with 4% rubber powder was obtained in the processing time of 90 days, which is about 12.27 MPa and shows a decline of about 16% compared to the lime concrete sample in the same processing time.

Figure (8) shows the effect of adding different percentages of rubber powder on the elasticity modulus of lime concrete at different processing times. The obtained results present the modulus of elasticity of the lime concrete samples containing rubber powder is 1-6% less than that of the samples without additives in all processing times, which indicates that the low impact of rubber powder on the elasticity modulus. As it is clear from the diagram, the modulus of elasticity for different percentages of rubber powder increases with an almost gentle and uniform slope as the processing time grows. Also, the modulus of elasticity decreases with an increase in the percentage of rubber powder and at the same processing time. The highest modulus value belongs to the sample containing 4% rubber powder and the processing time of 90 days.

Figure (9) presents the effect of adding different percentages of rubber powder on the shear modulus of lime concrete at different processing times. As it is seen, adding rubber powder to the lime concrete reduces the shear modulus. The lowest amount of shear modulus in all processing times is related to the lime containing 30% rubber powder and the highest is associated to the sample containing 4% plastic powder. So, it is evident that increasing the percentage of rubber powder decreases the shear modulus, and the difference of the shear modulus for the two different percentages of 4 and 30% in various processing times is about 40%. Also, according to Figure (9), increasing the processing time in all percentages causes a rise in the shear modulus. It is noteworthy that while the percentage of plastic increases from 8 to 30%, the rate of increase in the modulus of elasticity in the period of 28-90 days is lower than when the percentage of plastic powder is increased from 4 to 8%.

Figure (10) depicts the effect of adding different percentages of rubber powder on the bulk modulus of lime concrete at different processing times. Accordingly, the bulk modulus of the samples containing the rubber powder additive is lower than the lime concrete sample without plastic powder. As it is clear in the figure, along with the increase of plastic percentage from 4 to 30%, bulk modulus initially decreases rapidly, which is followed by a gradual reduction in slope. Also, the lowest and highest bulk modulus in all processing times correspond to the samples containing 30% and 4% rubber powder, respectively. However, the amount

of bulk modulus rises with the increase in the processing time for the samples conferring different percentages of plastic powder.

3.1.3. Lime concrete containing rubber fibers

It is inferred from Figure (11) that the addition of rubber fibers causes a relatively high increase in the maximum compressive strength compared to the samples of lime concrete with or without rubber powder. Adding 0.5% and 1% of rubber fibers at the same time of processing increased the strength followed by diminished compressive strength with the addition of larger amounts of rubber fibers.

Based on Figure (12), the fracture strain of the lime concrete samples containing rubber fibers is more than the other manufactured samples, which indicates the reduction of brittleness of the samples and the increase of their ductility. Increasing the percentage of rubber fibers at a constant processing time and increasing the processing time at the same fiber percentage will, respectively, decrease and increase the fracture strain.

Figure (13) shows that the secant modulus of the lime concrete samples containing rubber fibers is higher than that of the lime concrete samples with or without rubber powder. The increase in the processing time at a fixed percentage of rubber fibers, and increasing the percentage of rubber fibers in the same processing time, respectively, increases and decreases the secant modulus.

According to the results of Figure (14), the modulus of elasticity of the lime concrete samples containing rubber fibers is higher than that of the lime concrete samples with or without rubber powder. Similar to the secant modulus, the increase of the processing time at a fixed percentage of rubber fibers increases the elasticity modulus, while the increase in the percentage of rubber fibers in the same processing time decreases the amount of elasticity modulus.

Figure (15) demonstrates the fact that the shear modulus of the lime concrete sample containing rubber fibers is higher than that of the lime concrete samples with and without rubber powder. Increasing the processing time at a fixed percentage of rubber fibers leads to increase of the shear modulus, while as the percentage of rubber fibers in the same processing time grows, the shear modulus declines.

The fact that the bulk modulus of the lime concrete samples containing rubber fibers is higher than those with or without rubber powder is observed through Figure (16). As it is seen, the increase in the processing time at a fixed percentage of rubber fibers causes an increase in the bulk modulus, while increasing the percentage of rubber fibers at the same processing time, decreases the bulk modulus.

The results related to the fracture strain of the fly ash-lime concrete samples are about 20% higher than those of the lime concrete samples, which shows the increase in plasticity and ductility of the former compared to the latter. As regards the other geotechnical parameters, the moduli of secant, elasticity, shear and bulk of lime-fly ash is higher than that of the lime concrete at all processing times. The process of changing these moduli with the increase of the processing time is similar to the lime shaft sample.

3.2. Mechanical properties of fly ash-lime concrete with and without additives

Tables 7 and 8 summarize the mechanical parameters of the fly ash-lime concrete samples with and without additives. By comparing Tables (5) and (6), it can be deduced that the maximum compressive strength of the fly ash-lime concrete is higher than that of the lime concrete, and it is almost twice as much in the longer processing times of 28 and 90 days.

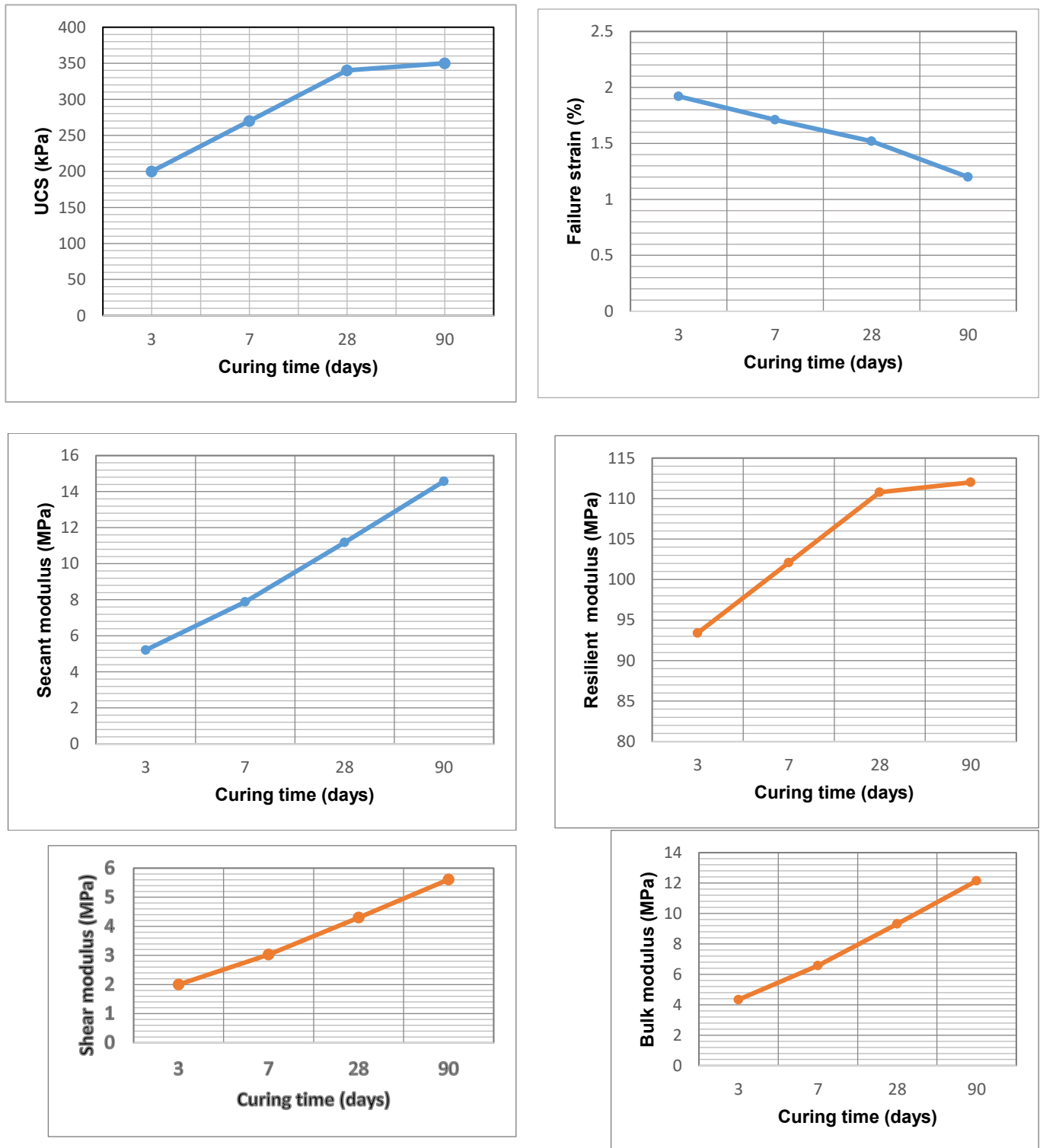


Figure 4. Mechanical parameters of lime concrete samples at different processing times

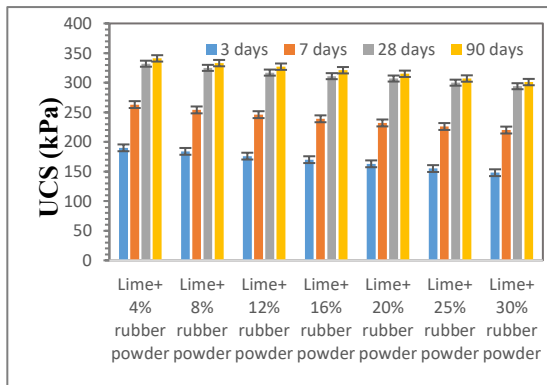


Figure 5. Effects of adding the rubber powder on the maximum compressive strength of lime concrete samples

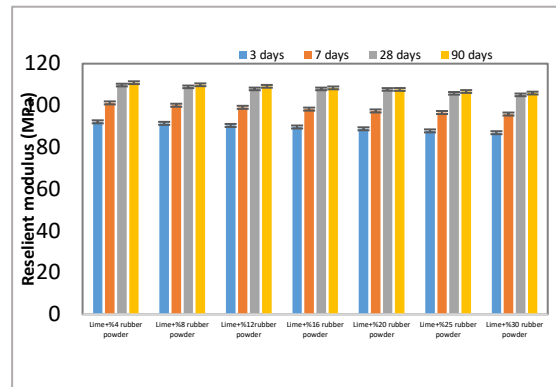


Figure 6. Effects of adding the rubber powder on the modulus of resilience of lime concrete samples at different processing times

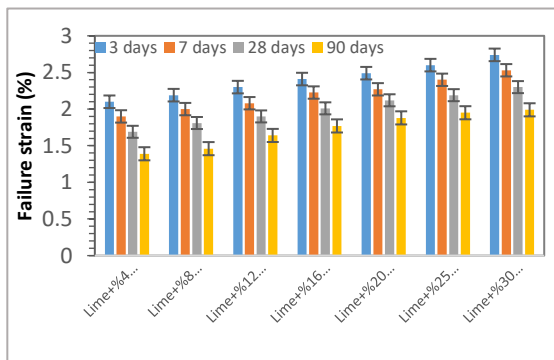


Figure 7. Effects of rubber powder on the maximum strain of lime concrete samples during processing times

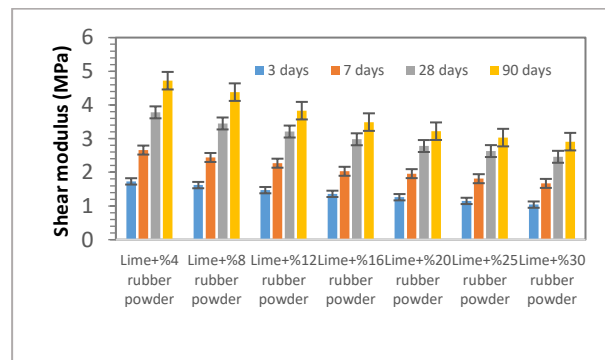


Figure 8. Effects of adding the rubber powder on the shear modulus of lime concrete samples at different processing times

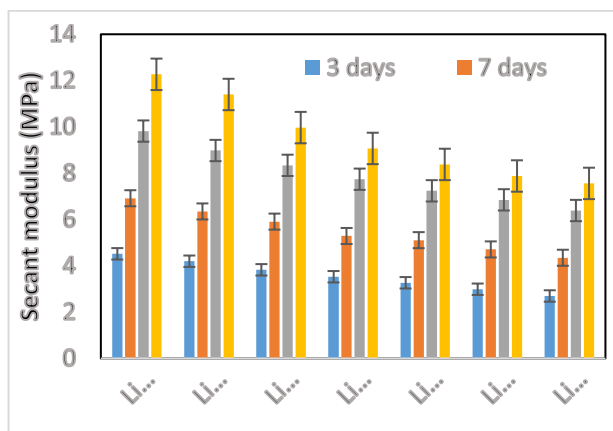


Figure 9. Effects of adding different percentages of rubber powder on the secant modulus of lime concrete at different processing times

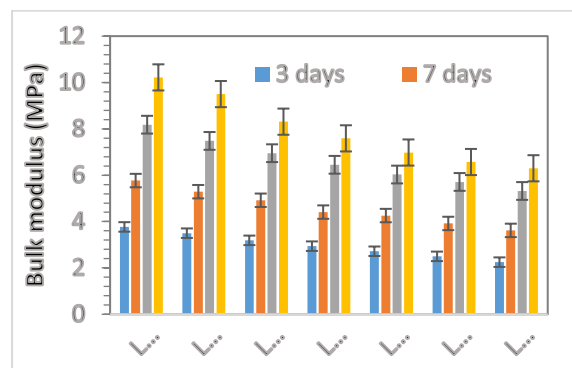


Figure 10. Effects of adding different percentages of rubber powder on the bulk modulus of lime concrete samples during processing times

Figure 11. Effects of adding different percentages of rubber fibres on the maximum compressive strength of lime concrete samples at different processing times

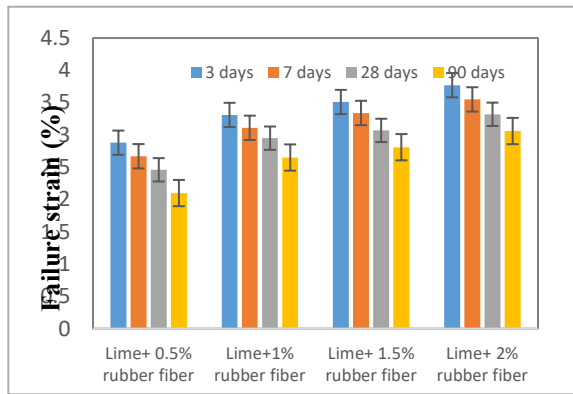


Figure 12. Effects of adding different percentages of rubber powder on the failure strain of lime concrete samples at different processing times

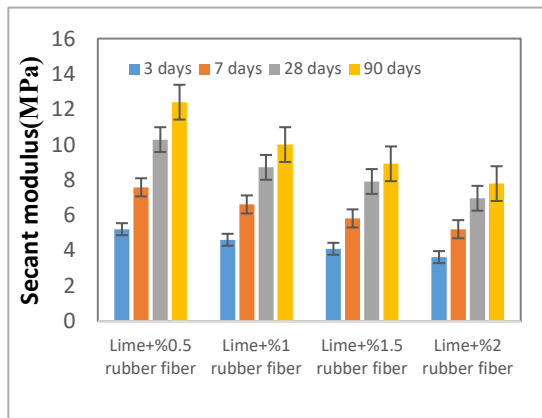


Figure 13. Effects of adding different percentages of rubber powder on the secant modulus of lime concrete samples during different processing times

Figure 14. Effects of adding different percentages of rubber fibres on the resilient modulus of lime concrete samples at different processing times

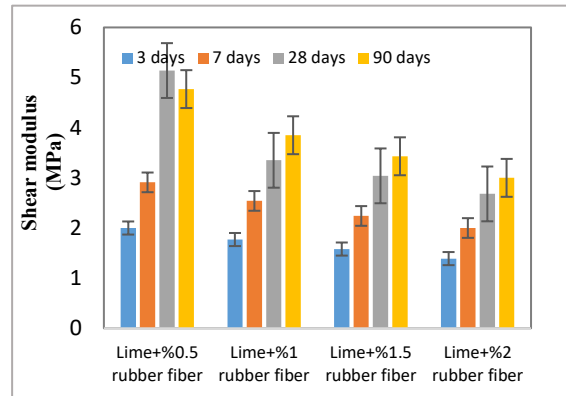


Figure 15. Effects of adding different percentages of rubber fibres on the shear modulus of lime concrete samples at different processing times

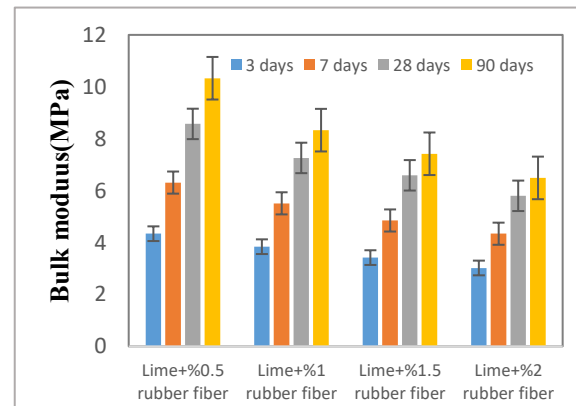


Figure 16. Effects of adding different percentages of rubber fibre on the bulk modulus of lime concrete samples during processing times

Table 6: Geotechnical parameters of mixture of lime and fly- ash samples with different percentages of rubber powder

Mix design	Curing day (days)	UCS (kPa)	Failure strain (%)	Secant modulus (MPa)	Resilient modulus (MPa)	Shear modulus (MPa)	Bulk modulus (MPa)
Lime	3	200	1.92	5.21	93.4	2.00	4.34
	7	270	1.71	7.89	102.08	3.03	6.58
	28	340	1.52	11.18	110.76	4.30	9.32
	90	350	1.20	14.58	112	5.61	12.15
Lime+ 4% rubber powder	3	190	2.10	4.52	92.16	1.73	3.77
	7	263	1.90	6.92	101.21	2.66	5.77
	28	332	1.69	9.82	109.76	3.78	8.18
	90	341	1.39	12.27	110.88	4.72	10.22
Lime+ 8% rubber powder	3	184	2.19	4.20	91.42	1.62	3.50
	7	254	2.00	6.35	100.09	2.44	5.29
	28	325	1.81	8.98	108.90	3.45	7.48
	90	333	1.46	11.40	109.89	4.38	9.50
Lime+ 12% rubber powder	3	176	2.30	3.83	90.42	1.47	3.19
	7	246	2.08	5.91	99.10	2.27	4.92
	28	317	1.90	8.34	107.91	3.21	6.95
	90	327	1.64	9.97	109.15	3.83	8.31
Lime+ 16% rubber powder	3	170	2.41	3.53	89.68	1.36	2.94
	7	239	2.26	5.29	98.24	2.03	4.41
	28	311	2.01	7.74	107.16	2.98	6.45
	90	321	1.77	9.07	108.40	3.49	7.59
Lime+ 20% rubber powder	3	163	2.49	3.27	88.81	1.26	2.72
	7	232	2.27	5.11	97.37	1.96	4.26
	28	307	2.12	7.24	106.67	2.78	6.03
	90	315	1.88	8.38	107.66	3.22	6.98
Lime+ 25% rubber powder	3	155	2.60	2.99	87.82	1.15	2.50
	7	226	2.40	4.71	96.62	1.81	3.92
	28	300	2.19	6.85	105.80	2.63	5.71
	90	307	1.95	7.88	106.67	3.03	6.57
Lime+ 30% rubber powder	3	148	2.74	2.70	86.95	1.04	2.25
	7	220	2.53	4.35	95.88	1.67	3.62
	28	294	2.30	6.39	105.06	2.46	5.32
	90	301	1.99	7.56	105.92	2.91	6.30

Table 7: Geotechnical parameters of mixture of lime and fly- ash samples with different percentages of rubber fibers

Mix design	Curing day (days)	UCS (kPa)	Failure strain (%)	Secant modulus (MPa)	Resilient modulus (MPa)	Shear modulus (MPa)	Bulk modulus (MPa)
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Lime	3	200	1.92	5.21	93.4	2.00	4.34
	7	270	1.71	7.89	102.08	3.03	6.58
	28	340	1.52	11.18	110.76	4.30	9.32
	90	350	1.20	14.58	112	5.61	12.15
Lime+ 0.5% rubber fibers	3	300	2.88	5.21	105.80	2.00	4.34
	7	405	2.67	7.58	118.82	2.91	6.31
	28	506	2.46	10.28	131.34	5.14	8.57
	90	521	2.10	12.40	133.20	4.77	10.33
Lime+ 1% rubber fibers	3	305	3.31	4.61	106.42	1.77	3.84
	7	411	3.11	6.61	119.56	2.54	5.51
	28	514	2.95	8.71	132.33	3.35	7.26
	90	530	2.65	10	134.32	3.85	8.33
Lime+ 1.5% rubber fibers	3	288	3.51	4.10	104.31	1.58	3.42
	7	389	3.34	5.82	116.83	2.24	4.85
	28	486	3.07	7.91	128.86	3.04	6.59
	90	501	2.81	8.91	130.72	3.43	7.42
Lime+ 2% rubber fibers	3	274	3.77	3.63	102.57	1.39	3.02
	7	370	3.55	5.21	114.48	2.00	4.34
	28	462	3.32	6.96	125.89	2.68	5.80
	90	477	3.06	7.79	127.74	3.00	6.49

Table 8: geotechnical parameters of mixture of lime and fly- ash samples with different percentages of rubber powder

Mix design	Curing time (days)	UCS (kPa)	Failure strain (%)	Secant modulus (MPa)	Resilient modulus (MPa)	Shear modulus (MPa)	Bulk modulus (MPa)
Lime+ fly ash	3	261	2.30	5.67	100.96	2.18	4.72
	7	432	2.04	10.59	122.17	4.07	8.82
	28	679	1.83	18.55	152.80	7.13	15.45
	90	698	1.47	23.74	155.15	9.13	19.78
Lime+ fly ash+ 4% rubber powder	3	249	2.52	4.94	99.48	1.90	4.10
	7	422	2.27	9.29	120.93	3.57	7.74
	28	660	2.03	16.25	150.44	6.25	13.54
	90	684	1.66	20.60	153.42	7.92	17.17
Lime+ fly ash+ 8%rubber powder	3	240	2.58	4.65	96.87	1.79	3.88
	7	403	2.39	8.43	118.57	3.24	7.02
	28	645	2.16	14.93	148.58	5.74	12.44
	90	682	1.77	19.26	153.17	7.41	16.05
Lime+ fly ash+ 12%rubber powder	3	228	2.77	4.11	96.87	1.58	3.42
	7	391	2.48	7.88	117.08	3.03	6.57
	28	634	2.29	13.84	147.22	5.32	11.53
	90	820	1.93	21.24	170.28	8.17	17.70

Lime+ fly ash+	3	219	2.87	3.81	95.76	1.46	3.17
Lime+ fly ash+	7	379	2.71	6.99	115.60	2.69	5.82
16%rubber powder	28	622	2.44	12.74	145.73	4.89	10.67
Lime+ fly ash+	90	800	2.11	18.96	167.8	7.29	15.80
Lime+ fly ash+	3	212	2.99	3.54	94.89	1.36	2.95
Lime+ fly ash+	7	373	2.71	6.88	114.85	2.64	5.73
20%rubber powder	28	615	2.55	12.06	144.86	4.64	10.05
Lime+ fly ash+	90	787	2.20	17.89	166.19	6.89	14.90
Lime+ fly ash+	3	200	3.10	3.22	93.40	1.24	2.68
Lime+ fly ash+	7	360	2.85	6.31	113.24	2.43	5.26
25%rubber powder	28	603	2.61	11.55	143.37	4.44	9.62
Lime+ fly ash+	90	766	2.34	16.37	163.58	6.30	13.64
Lime+ fly ash+	3	197	3.26	3.02	93.03	1.16	2.52
Lime+ fly ash+	7	355	3.02	5.88	112.63	2.26	4.90
30%rubber powder	28	587	2.76	10.63	141.39	4.09	8.86
Lime+ fly ash+	90	752	2.37	15.86	161.85	6.10	13.22

Table 9: geotechnical parameters of mixture of lime and fly- ash samples with different percentages of rubber fibers

Mix design	Curing time (days)	UCS (kPa)	Failure strain (%)	Secant modulus (MPa)	Resilient modulus (MPa)	Shear modulus (MPa)	Bulk modulus (MPa)
Lime+ fly ash	3	261	2.30	5.67	100.96	2.18	4.72
	7	432	2.04	10.59	122.17	4.07	8.82
	28	679	1.83	18.55	152.80	7.13	15.45
	90	698	1.47	23.74	155.15	9.13	19.78
Lime+ fly ash+ 0.5%rubber fiber	3	389	3.40	5.72	116.87	2.20	4.77
	7	647	3.19	10.14	148.83	3.90	8.45
	28	1007	2.99	16.83	193.47	6.47	14.02
	90	1290	2.52	25.60	228.56	9.85	21.33
Lime+ fly ash+ 1%rubber fiber	3	395	3.95	5.00	117.58	1.92	4.17
	7	658	3.73	8.82	150.19	3.40	7.35
	28	1024	3.50	14.63	195.58	5.63	12.19
	90	1179	3.16	18.65	214.80	7.17	15.54
Lime+ fly ash+ 1.5%rubber fiber	3	374	4.13	4.53	114.97	1.74	3.77
	7	620	3.99	7.77	145.48	2.99	6.47
	28	971	3.69	13.16	189.00	5.06	10.97
	90	1249	2.41	18.31	223.48	7.04	15.26
Lime+ fly ash+ 2%rubber fiber	3	356	4.50	3.95	112.74	1.51	3.29
	7	593	4.26	6.96	142.13	2.68	5.77
	28	920	3.98	7.45	182.69	2.87	6.21
	90	1191	3.63	16.40	216.28	6.31	13.67

3.2.1. Lime-fly ash with and without additives containing rubber powder

Comparing the maximum compressive strength of the samples at various percentages and at the processing time of 90 days demonstrates the increasing trend of the compressive strength until the addition of 12% rubber powder, and then the compressive strength decreases. However, adding more than 8% rubber powder to lime-fly ash concrete increases the compressive strength compared to the samples without additives. Also, increasing the processing time reduces the fracture strain at all percentages. However, the fracture strain of the lime-fly ash concrete samples in all percentages and processing times is higher than those without rubber powder.

3.2.2. Lime-fly ash concrete with and without additives containing rubber fibers

The addition of rubber fibers to fly ash-lime concrete significantly increases the maximum compressive strength and failure strain compared to all the samples manufactured in this study. Even at some percentages of rubber fibers, the maximum compressive strength reached higher than 1000 kilopascals. Increasing the processing time at a fixed percentage of fibers and increasing the percentage of rubber fibers at a fixed processing time will decrease and increase the fracture strain, respectively.

The secant, shear, elasticity and bulk moduli of the samples containing rubber fibers were reported to be higher than the other samples of this research, and the change in them with increasing processing time and the percentage of fibers is similar to the lime-fly ash concrete samples containing rubber powder.

Besides, the maximum compressive strength in the soil-fly ash combination alone or in combination with lime increased slightly when the maximum of 4% fly ash is used. The strength with 6% addition and the processing time of 90 days is reported as the highest one.

4. Conclusion

In this research, the simultaneous effect of traditional additives with waste tire particles and recycled polymer materials upon soil improvement was investigated. The following results have been obtained based on the experiments conducted on the lime concrete and lime-fly ash concrete samples with additives:

- In the lime concrete samples, the addition of rubber powder causes a slight decrease in the maximum compressive strength while the rubber fibers had a better performance than the rubber powder and improve the compressive strength.
- In the lime concrete samples with or without rubber powder, increasing the processing time at a fixed percentage and increasing the percentage of rubber powder at a fixed processing time, respectively, increases and decreases the maximum compressive strength. As for the samples containing rubber fibers, with the increase in the percentage of rubber fibers, the strength increases too, from 0.5 to 1% and then a downward trend occurs.
- The fracture strain of the lime concrete samples containing rubber fibers is higher than that of the lime concrete samples with or without rubber powder which indicates the more ductility behavior of those samples. The increase in the processing time at a fixed percentage and the increase in the percentage of rubber powder at a fixed processing time will, respectively, decrease and increase the fracture strain.
- In the lime concrete samples with or without additives, increasing the processing time at a fixed percentage and increasing the percentage of rubber powder at a fixed processing time causes an increase and a decrease, respectively, in the secant, elasticity, shear and bulk moduli.
- The compressive strength of the lime-fly ash concrete samples with or without additives is higher than that of the lime concrete samples with or without additives.
- The compressive strength of the lime-fly ash concrete sample increases significantly with the addition of rubber fibers and reaches beyond 1000 kilopascals in 90 days processing time and at different percentages.

- Lime-fly ash concrete samples containing rubber fibers enjoy the highest fracture strain at all percentages and in all processing, times compared to the other samples in this research, which indicates their more ductility behavior.
- The impacts of processing time and increasing the percentage of the additives to the fly ash-lime concrete on all mechanical parameters is similar to the lime concrete samples.

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6. References

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